Radiation, Radiological Events and You

By

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Goals for Today

- Cover basics of radiation
- Discuss radiological events from terrorism or accidents
- Answer questions

- Not covering nuclear power related events

A word from my sponsor

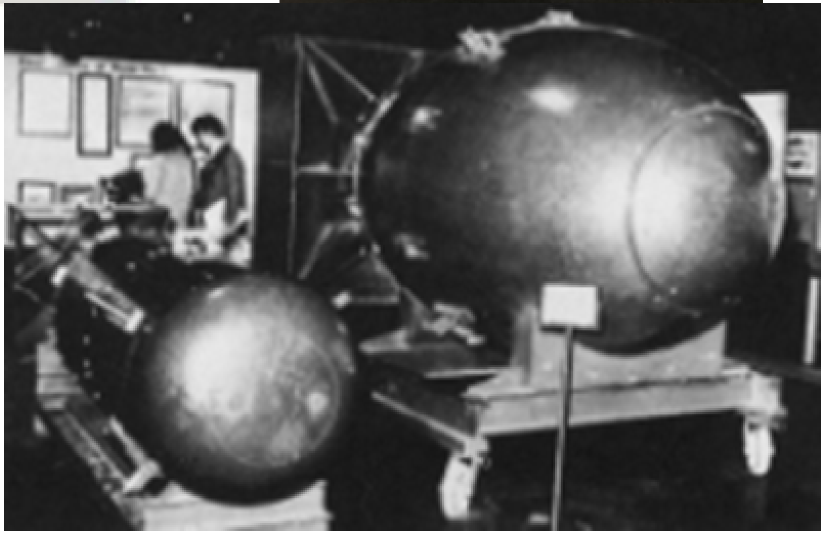
- **FHCRC**
  - – Seattle, WA
  - – Cancer research – prevention and treatment
  - – Established in 1975
  - – Broadscope biomedical research lab
  - – 3,000 employees, 600 radiation workers
  - – **3** Nobel prize winners

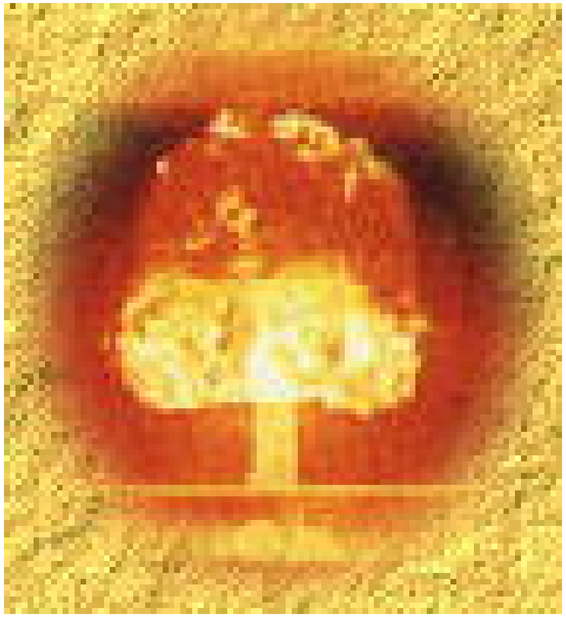
Introduction

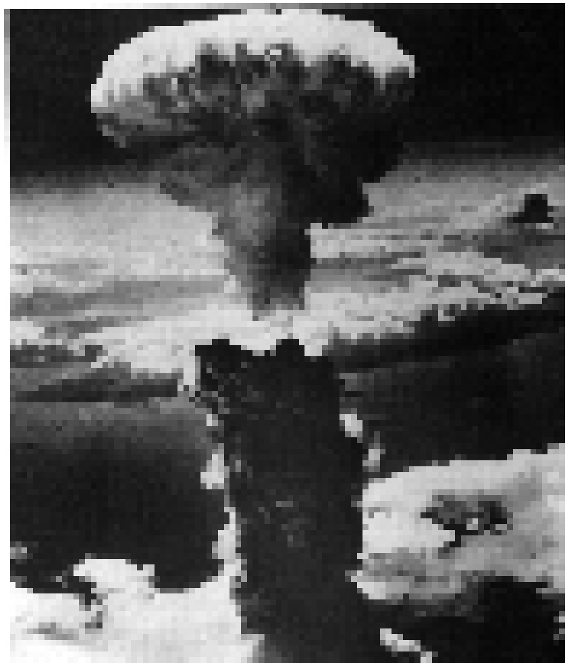
- A **Radiological Event** involves the accidental or purposeful release of radiation or radioactive materials into the public or environment
- This can create fear, injury and death and lead to severe disruption.
  - Fear is due to the public's general fear of radiation.
  - Injury and death may be the result of the explosive and could result from sufficient radiation exposure.
  - Disruption results from of panic and the cleanup of the radioactive material and any consequent avoidance of the radioactive location after clean up.

Public Perception

Radiation as seen by public





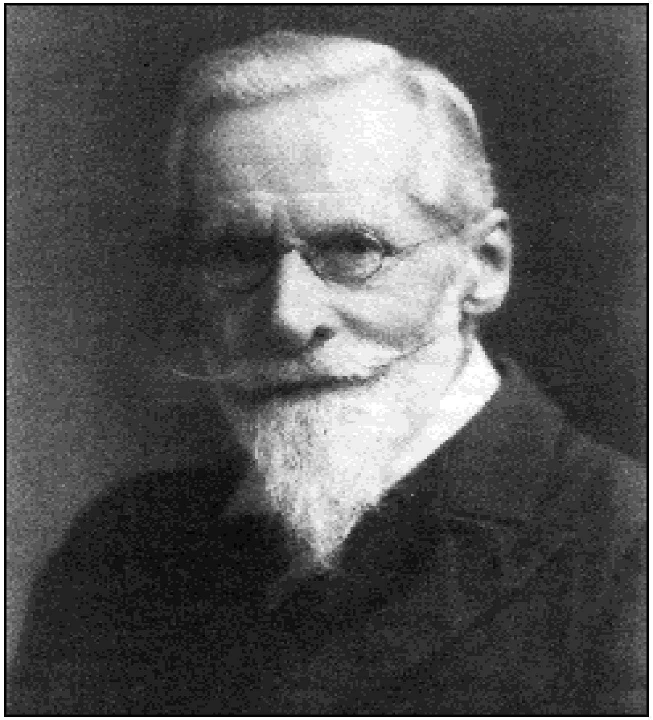


Reality

- Been studied for over 100 years
- Characterized very well
- Risk are well known for high levels
- Have a lot of human data
- Weak carcinogen
- Weak mutagen
- Saves **thousands** of lives

History

X-ray “Pre-history”



- 1869 William Crookes notes fogging of photographic plates in his laboratory and complains of defective packaging.
- This is caused by x-rays, which were unknown at the time and produced by Crookes Tubes in the laboratory.

Roentgen’s Discovery

- On November 8, 1895, Prof. W. Roentgen noted that the discharge from a Crookes tube or similar CRT (Cathode Ray Tube) resulted in fluorescence from a nearby paper screen covered with barium platinocyanide.
- Exhaustive research resulted in a paper published in December 1895 describing the unusual penetrating properties of this radiation.

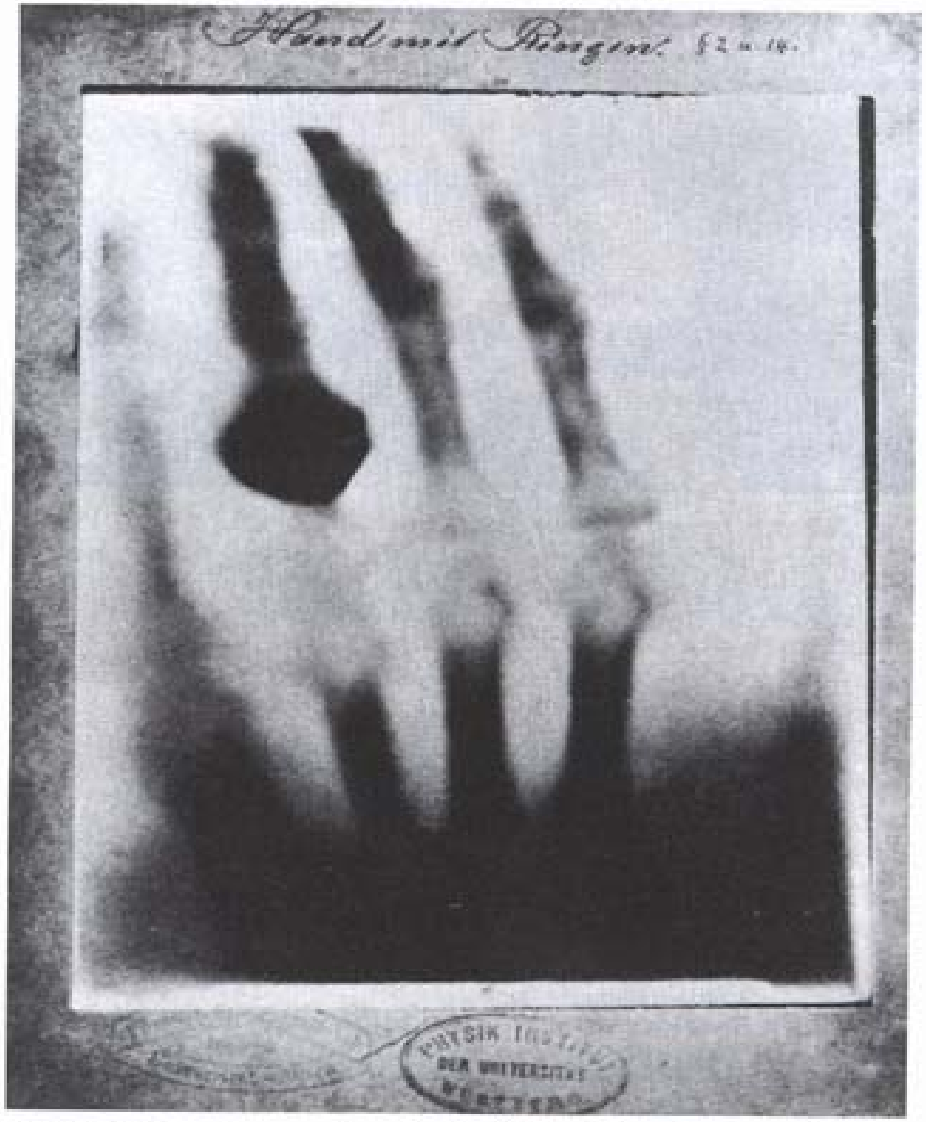
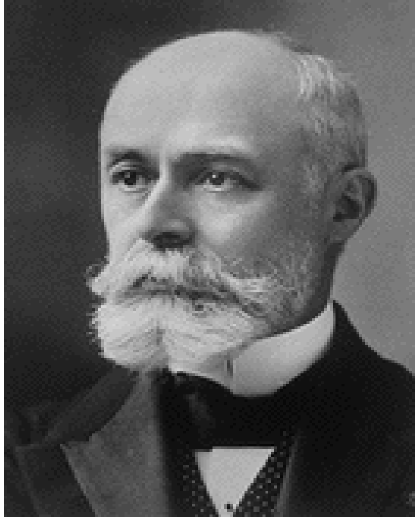

Hand mit Ringen. 82 u. 14.
PHYSIK INSTITUT DER UNIVERSITÄT WÜRZBURG

Fig. 1. X-ray image of a hand, believed to be that of Frau Roentgen, made by W. C. Roentgen on 22 December 1895. (Reproduced from *The Rays* by R. and E. Brecher with permission from The American College of Radiology Foundation.)

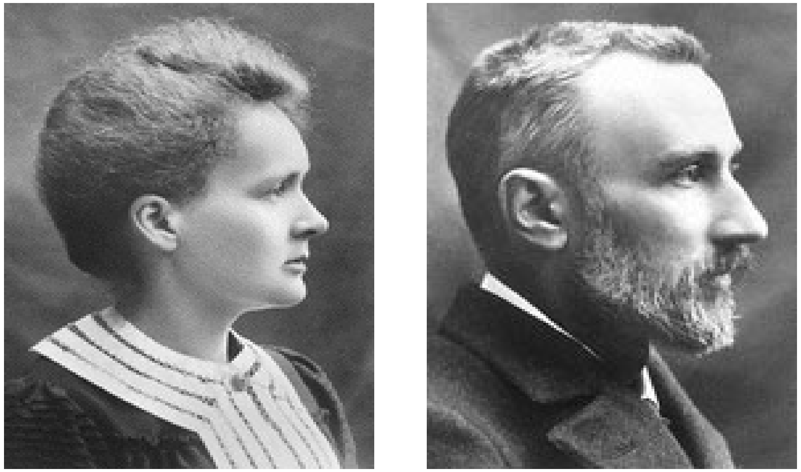
Frau Roentgen's Hand

December 22, 1895
First published x-ray

Radioactivity & Henri Becquerel



- Set about to find a natural source of these mysterious “x-rays” discovered by Roentgen.
- Discovered in March 1896 that a sample of natural uranium sulfate emitted some form of energy that would also fog photographic film without the addition of external energy.



Marie & Pierre Curie

- Isolated Radium from a sample of Uranium in 1898
- Verified that when sufficient quantities were in contact with the skin it would cause a burn and then a more serious wound.
- Pioneered the use of Radium for radiotherapeutic treatment of tumors and other malignancies

Initial Use of Radiation

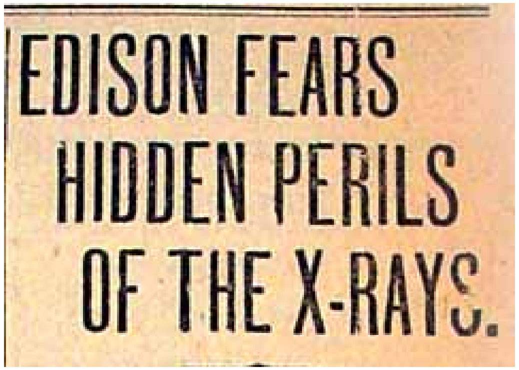
- X-rays
  - Medical (diagnostic and therapeutic)
  - Research
  - Commercial
- Radioactive Materials
  - Medical
  - Consumer
  - The “magic” of Radium

Injuries Reported

- In May 1896 T. Edison reports that eye injuries may be the result of x-ray exposures.
- Skin reddening also appears on both staff and patients.
- Early injuries often ignored because of the latent effect of radiation.
- Physicist and physicians also refuse to believe that x-rays were hazardous.

The World.

From New York World, August 3, 1903 page 1.



EDISON FEARS HIDDEN PERILS OF THE X-RAYS.

Edison Fears

- Laboratory Employee Loses Hand and Arm
- The circumstances involved the intentional exposure of arms and hands to fluoroscopic resulting in significant injury.
- Edison quits experimenting with x-rays shortly after Dally’s death.

First X-ray Attributed Fatality - October 1904

- Clarence M. Dally, a glass blower at the Thomas Edison's Menlo Park Lab, is the first person known to have been killed by x-ray exposure.
- He was severely burned in 1896, he still worked with x-rays until 1898.

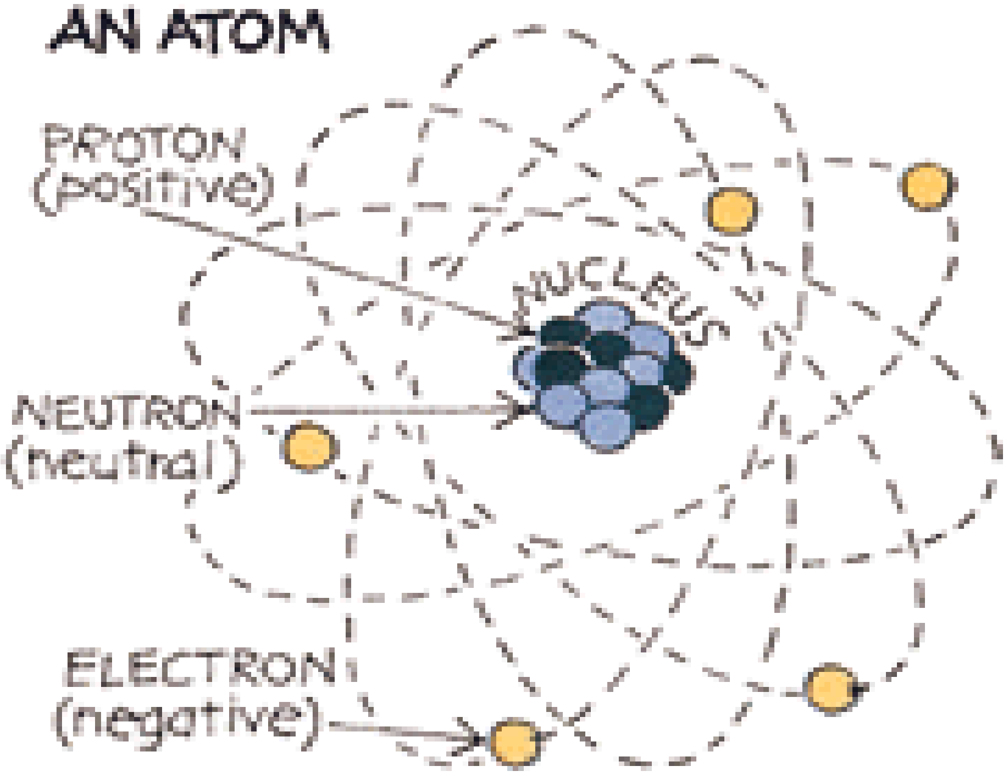
Present Day Use

- 300,000,000 x-ray given annually in US.
- 20 Million Nuclear Medicine studies
- 100+ nuclear power plants in US
- Other uses include - research, industrial uses, space applications, food safety, military, medicine

Basics of Radiation

The Atom

- Nucleus
  - Protons
  - Neutrons
  - Stability of the nucleus determined by the number of neutrons and protons
- Extra-nuclear
  - Electrons

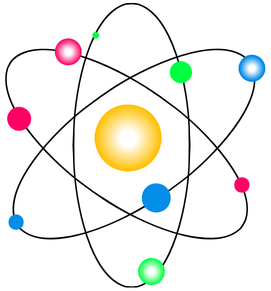


Radiation

- **Radiation:** Energy in transit, either as particles or electromagnetic waves
- **Ionizing Radiation:** Radiation with enough energy to cause an electron to leave an atom
- 4 main types
  - Alpha particles
  - Beta Particles
  - Neutrons
  - Gamma and X-ray

Non-Ionizing Radiation

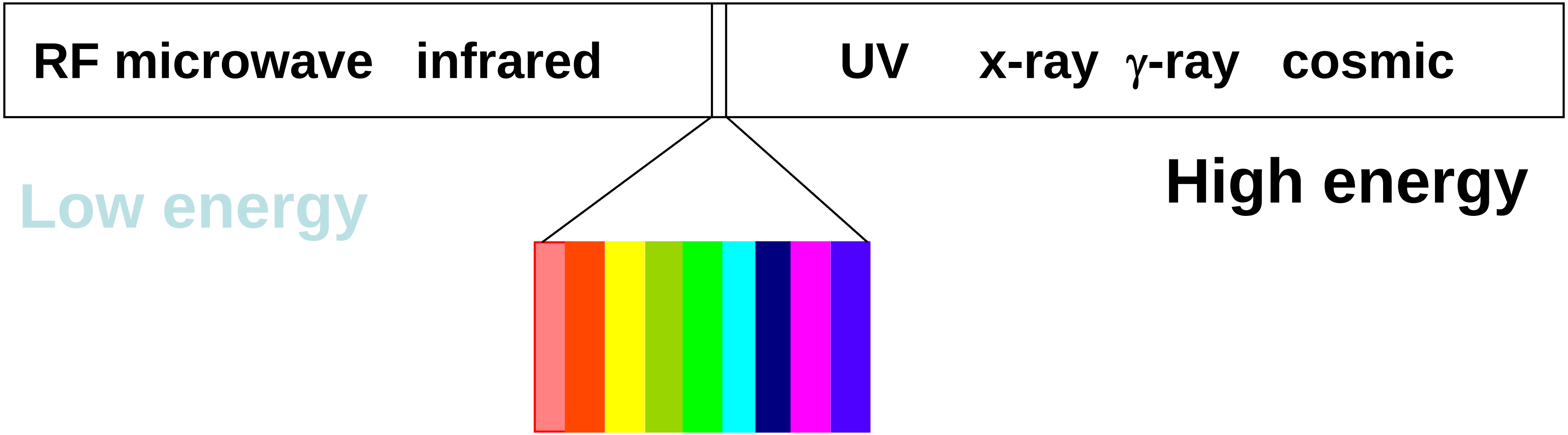
- Radiation which does not have enough energy to cause ions to be formed upon interaction
  - Radio waves
  - Microwaves
  - Visible light
  - UV
- Note that today when I say radiation, I mean ionizing radiation



Electromagnetic Spectra

Long wave length

Short wave length



RF microwave infrared

UV x-ray γ-ray cosmic

Low energy

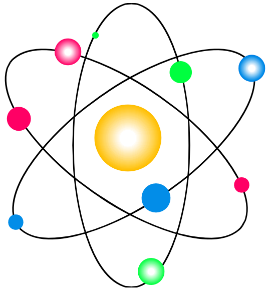
High energy

visible

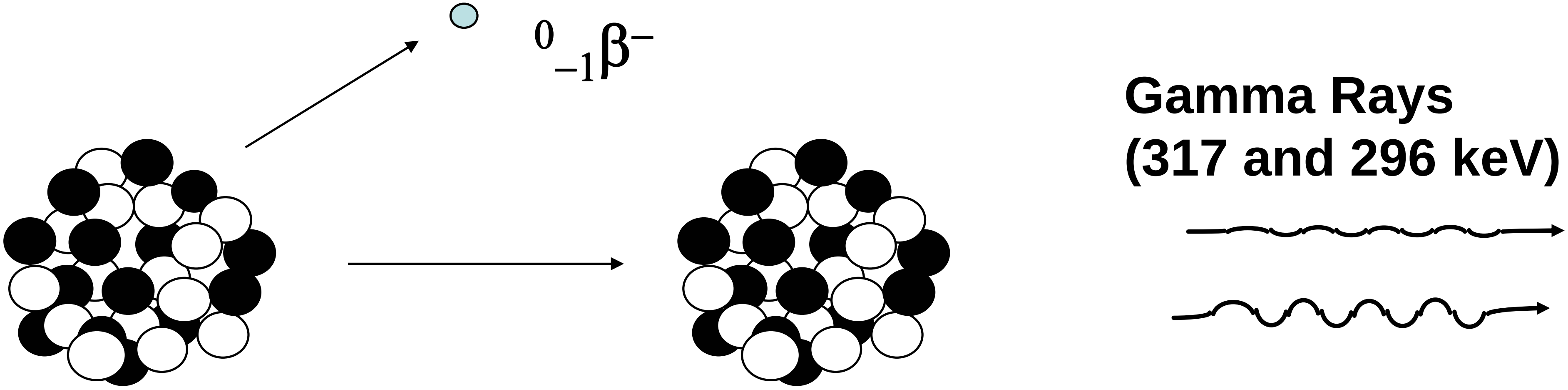
NOTE: NOT TO SCALE!!!

Radioactive Material

- *Radioactive material* consists of atoms with unstable nuclei
- The atoms spontaneously change (decay) to more stable forms and emit radiation
- A person who is *contaminated* has radioactive material on their skin or inside their body



Example of Radioactive Material



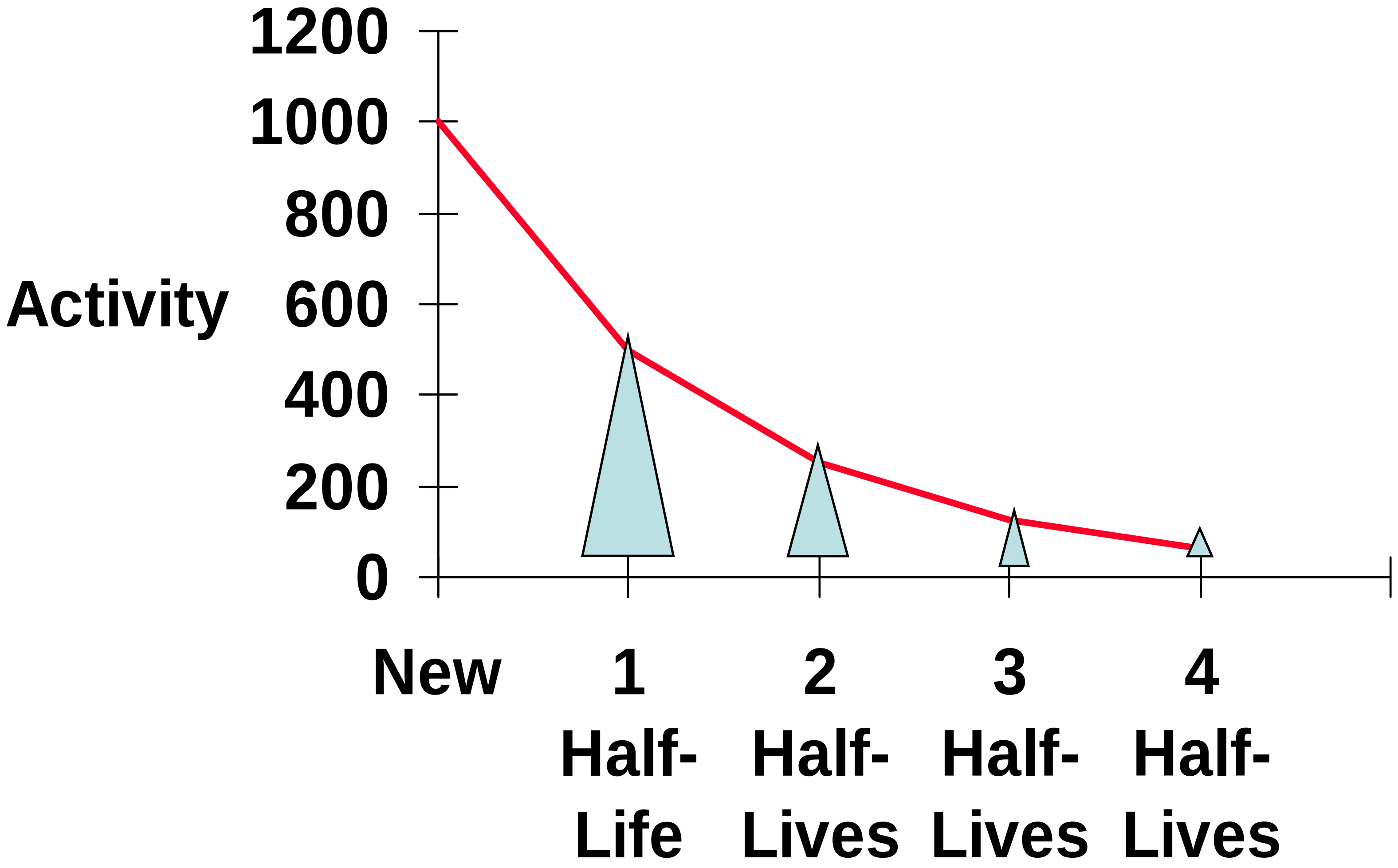
$^{0}_{-1}\beta^{-}$

Gamma Rays
(317 and 296 keV)

Parent Nucleus
Ir-192

Daughter Nucleus
Pt-192

Half-Life


1200
1000
800
Activity
600
400
200
0
New
1
Half-
Life
2
Half-
Lives
3
Half-
Lives
4
Half-
Lives

Fission and Fusion

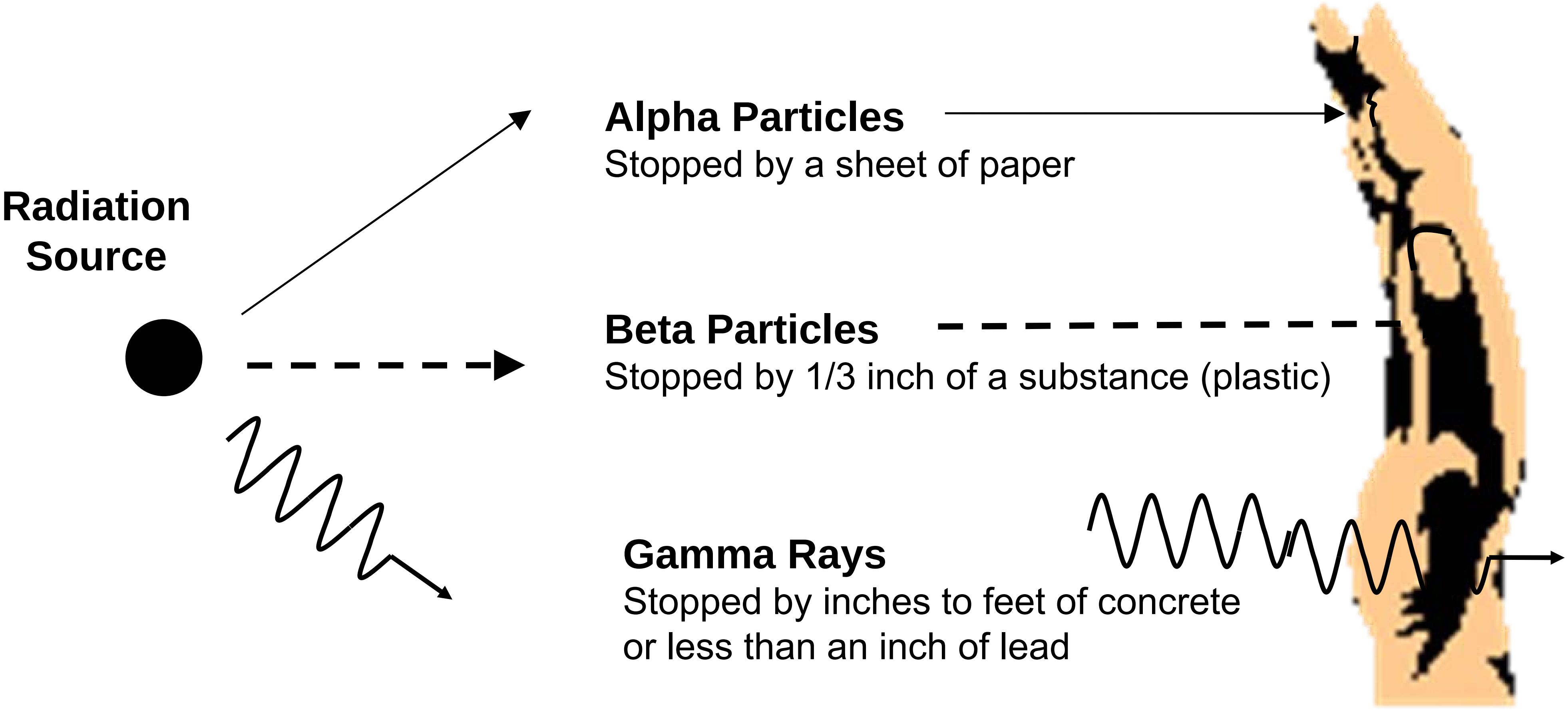
- Fission is the splitting of a heavy atom
  - neutron + U235 yields energy and fission products
  - Also yields more neutrons – chain reaction

- Fusion is the combining light atoms
  - H + H yields energy and He
  - Heat causes more fusion – chain reaction

Radiation Interactions with Matter

- Radiation with enough energy causes ions to be formed
- The amount of ions formed is based on the energy deposited
- Use this principle to our advantage for shielding
- Causes all effects of radiation – good and bad

Common Types of Ionizing Radiation



Radiation Source

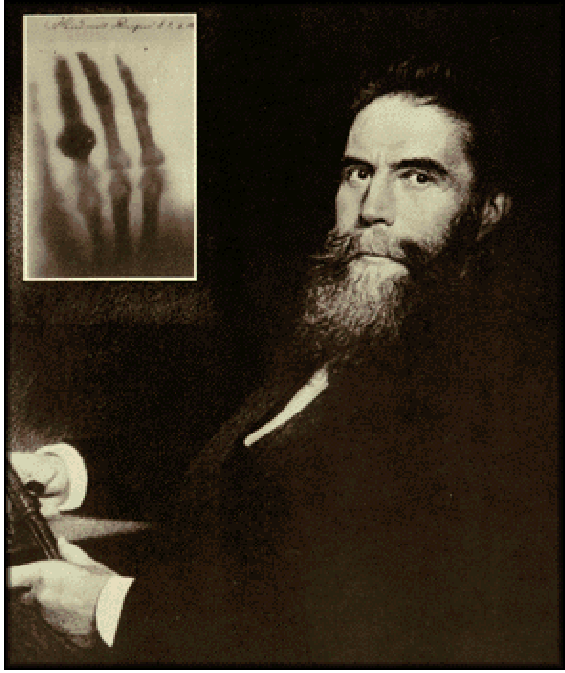
Alpha Particles
Stopped by a sheet of paper

Beta Particles
Stopped by 1/3 inch of a substance (plastic)

Gamma Rays
Stopped by inches to feet of concrete
or less than an inch of lead

Units

Roentgen (R)



- Measure of *exposure*
- Charge produced in a specific volume by gamma or x-rays
- 1 R = 2.58 x 10^{-4} C/kg
- SI unit is C/kg
- Meters (Ion Chambers and GM detectors) often read out in mR/hr

RAD

- Radiation Absorbed Dose
- Energy deposited per unit mass
- 1 rad = 100 erg/gm
- Does not account for different radiation damages
- SI unit is the gray (Gy)
- 100 rad = 1 Gy

REM

- Measure of Biological Damage
- Effective Dose Equivalent
- Dose Effective
- TEDE and CEDE
- rad x QF = rem
- SI unit is sievert (Sv)
- 100 rem = 1 Sv

Good News

- For x-ray, beta and gamma radiation

$$\mathbf{1\ R \cong 1\ rad \cong 1\ rem}$$

- For alpha and neutron, have to take into account the quality factor

rad x QF = rem

- QF for alpha is 20, neutron 2-20, gamma/beta is 1

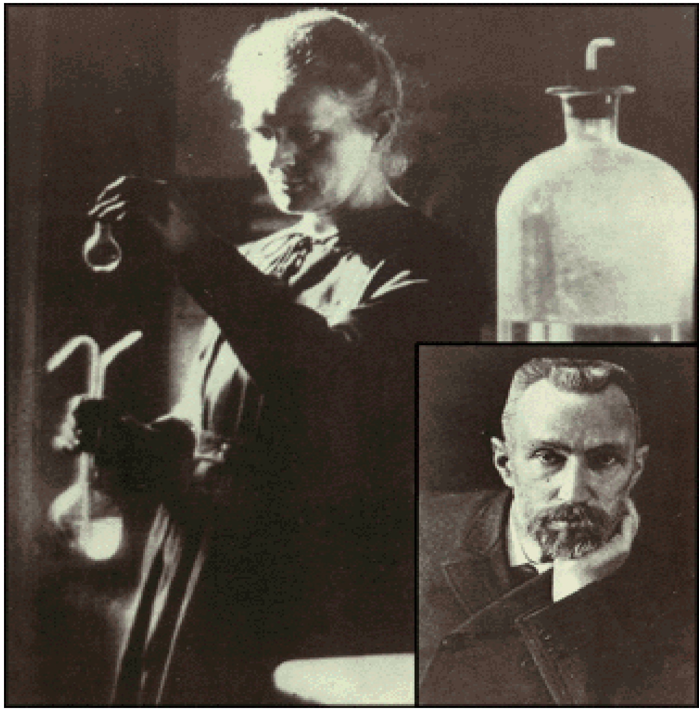
Measures of Radioactivity

The quantity of radioactive material present at a given time:

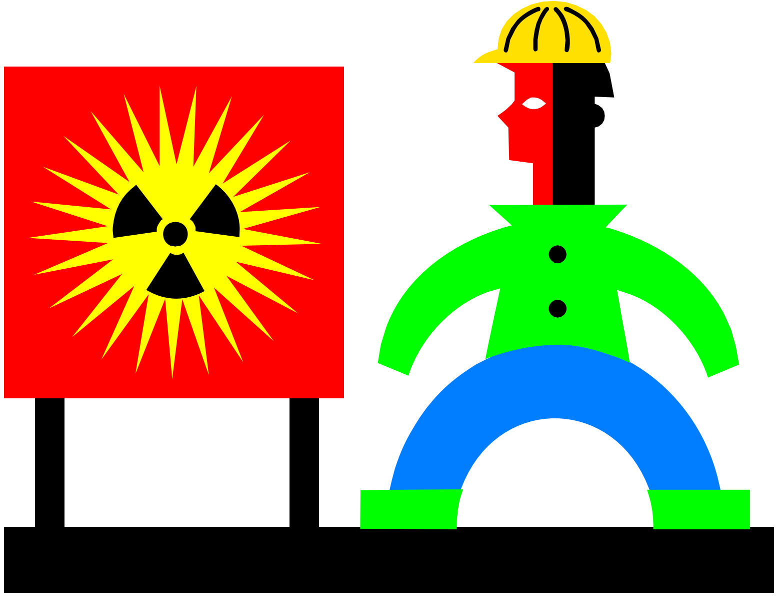
Unit is the **Curie (Ci)**

1 Ci is equal to

3.7×10^{10} disintegration per second (dps)

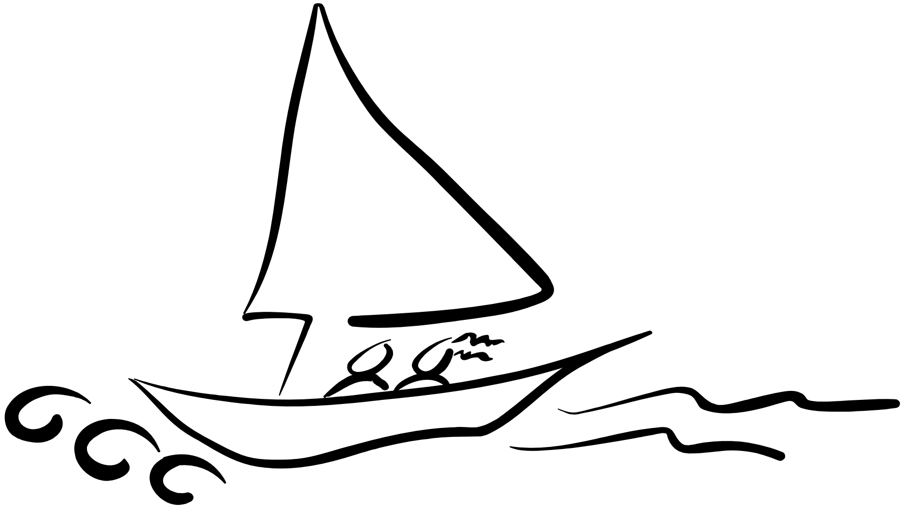


Radiation Dose



Sources of Radiation

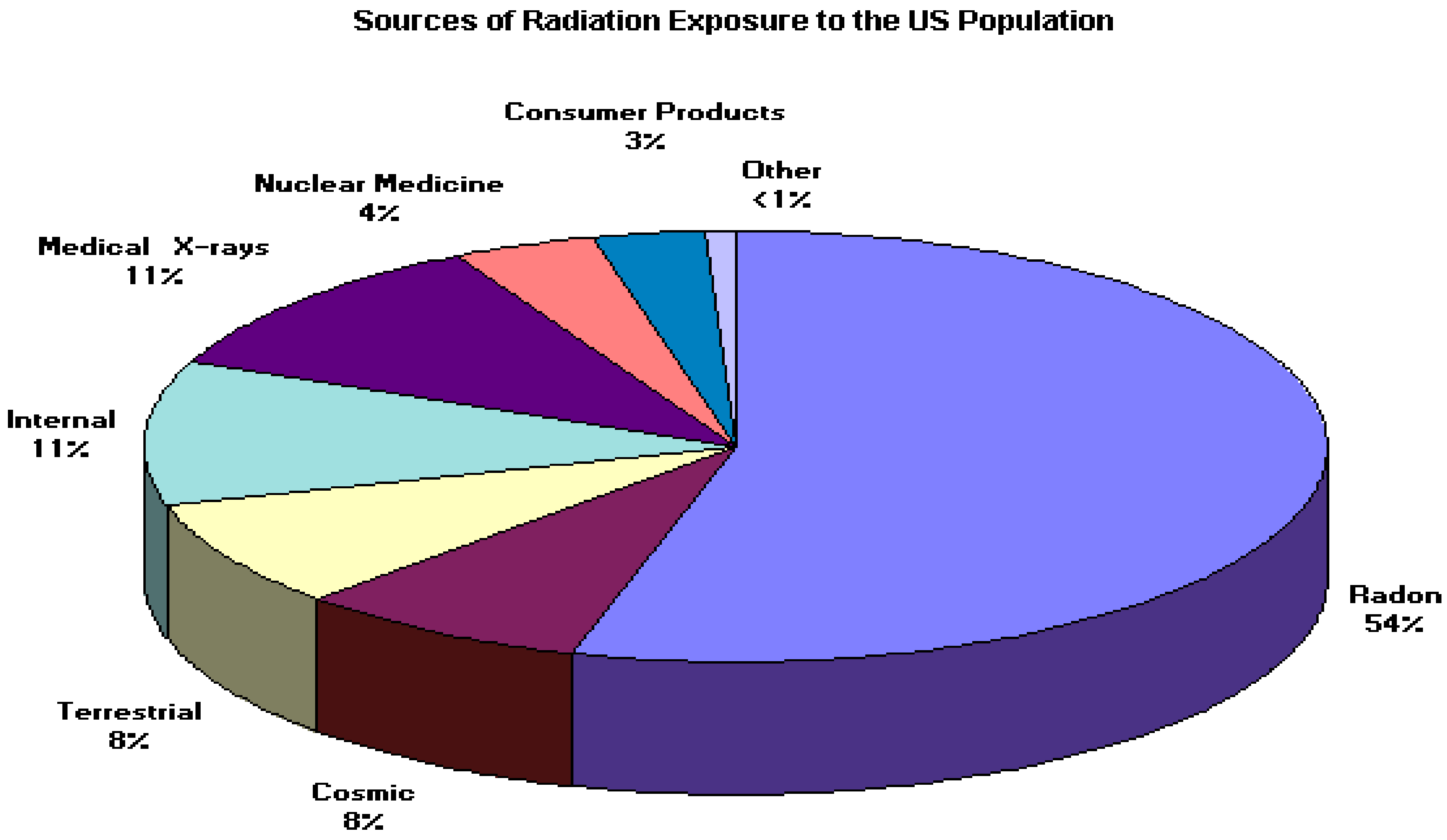
- Natural - Sea of Radiation
  - Radon
  - Cosmic
  - Terrestrial
- Human-produced
  - Nuclear Medicine
  - Cancer Therapy
  - Nuclear power



Factors in Background

- Location, location, location
  - Radon
  - Cosmic
  - Terrestrial
- Flying
- X-rays and nuclear medicine
- Smoking

Average Annual US Dose
360 mrem



Radiation Dose in People

- Trillions of cells make up the body
- Cells --> Tissue --> Organs -->Body
- Active cells are more radio-sensitive
  - White blood cells, Bone marrow, Stomach lining, Hair follicles

- Inactive cells are radio-insensitive
  - Bone, Muscle, Tendon, Nerves, Skin

Radiation Damage - Ionization

- Radiation causes *Ions and free radicals* in cell

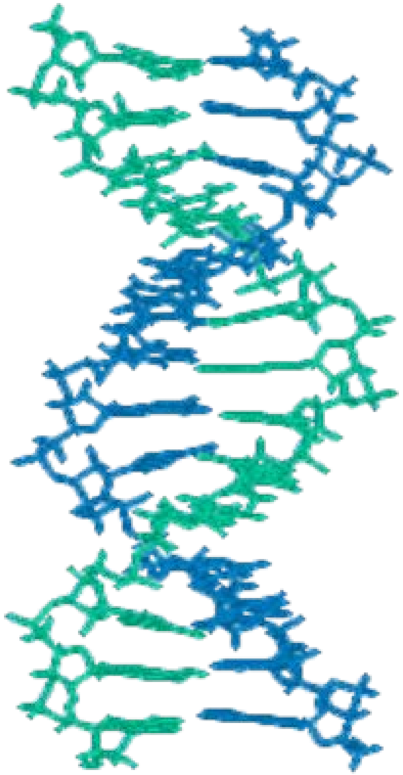
ex: Radiation + H_20 -> OH^- + H•

- These free radicals and ions react with parts of the cell
  - attack sensitive areas
  - cause damage
- May have direct damage to “targets” also

Damage - Cell

- Most Critical Target in Cells - DNA
  - Damage DNA
  - MAY cause effects to the cell
  - H_2O coating is primary target

  - Single breaks (SSB)
  - Double strand breaks (DSB)

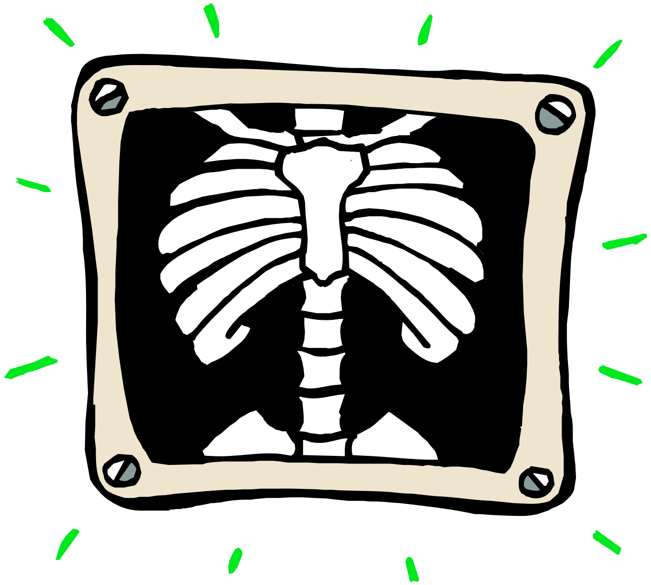


Damaged Cells

- Once Damaged, the Cell May:
  - Repair the damage - No problem
    - Damaged cells held in cell cycle
    - Enzymes repairs SSB and some DSB
  - Die - No problem on **small** basis
    - 1% of cells die each day
    - No longer working
  - Mis-repair/non-repair – BAD
  - Too many dead cells – BAD

Health Effects

- From cell to health effects
- Cells --> Tissue --> Organs -->Body
- Effects Depends on
  - dose rate (Acute or Chronic)
  - **dose**
  - type of radiation
  - location of dose



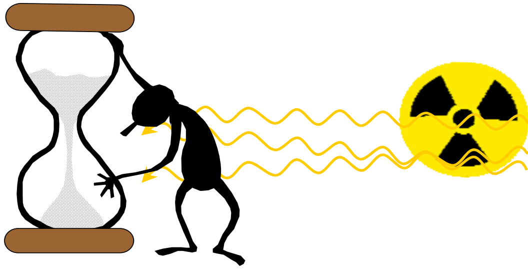
Typical Radiation Doses

Flight from Los Angeles to New York	**3 mrem**
Chest X-ray	**10 mrem**
Annual background	**360 mrem**
Radiographers annual (1993 Value)	**540 mrem**
CT Scan	**780 mrem**
Annual radworker WB dose limit	**5,000 mrem**
Acute radiation syndrome	**100,000 mrem**
LD50/60 for humans	**350,000 mrem**
Radiation therapy	**1,200,000 mrem**

Exposure Pathways

- Direct radiation
- Ingestion
- Inhalation

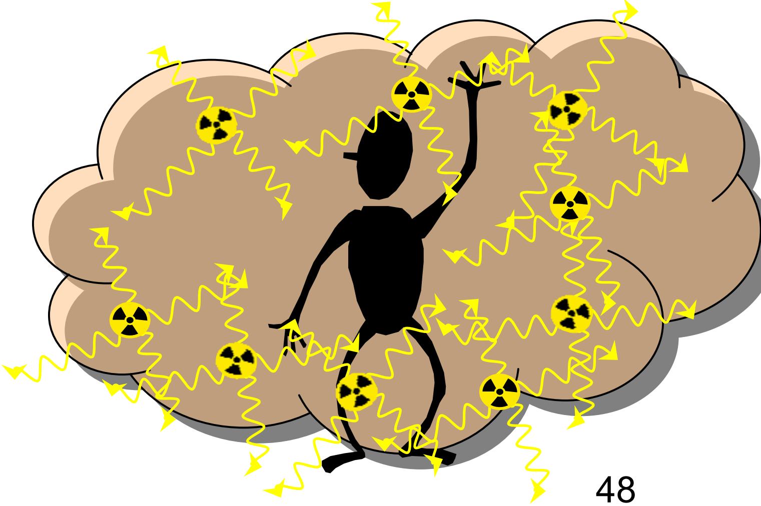
- Wounds
- Direct injection



Direct

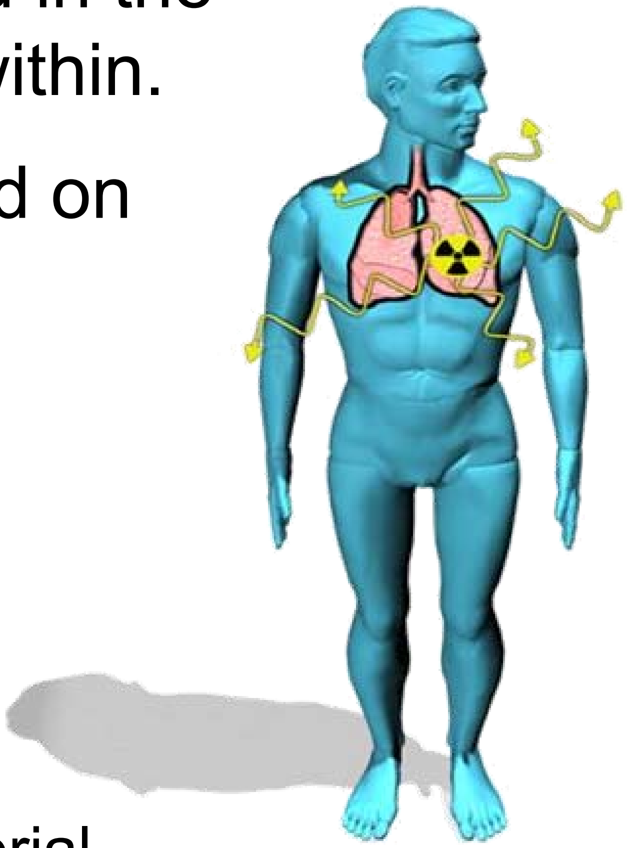
Direct whole body exposure from:

- A passing radioactive cloud or smoke
- A large source
- Exposure from contamination



Internal Exposures

- Once radioactive material is deposited in the body, it can expose the person from within.
- The magnitude of the dose will depend on many factors:
  - How much material was deposited
  - How it got into the body
  - Chemical form
  - the radiation it produces
  - How quickly it decays, and
  - How quickly the body eliminates the material



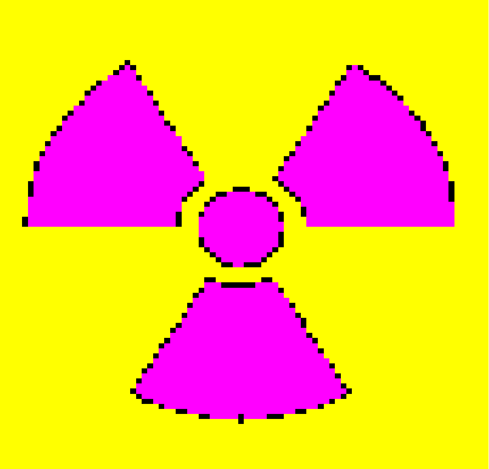
Ways to Minimize Dose

- Direct
  - Reduce Time
  - Increase Distance
  - Use Shielding
- Internal and Contamination
  - Prevention
  - Intervention

Effects and then there are Effects

- Whole Body Acute
- Partial Body Acute

- Whole Body Chronic
  - Somatic
  - Heritable



Radiation Effects

- Skin burns
  - >600 rads to skin
- Acute effects
  - Radiation sickness > 100 rads
  - In 30 days Death > 350 rads
  - "Immediate" Death > 2000 rads
- Long term effects
  - Cancer – 8% increase for 100 rads lifetime

Actions for Acute High Dose WB

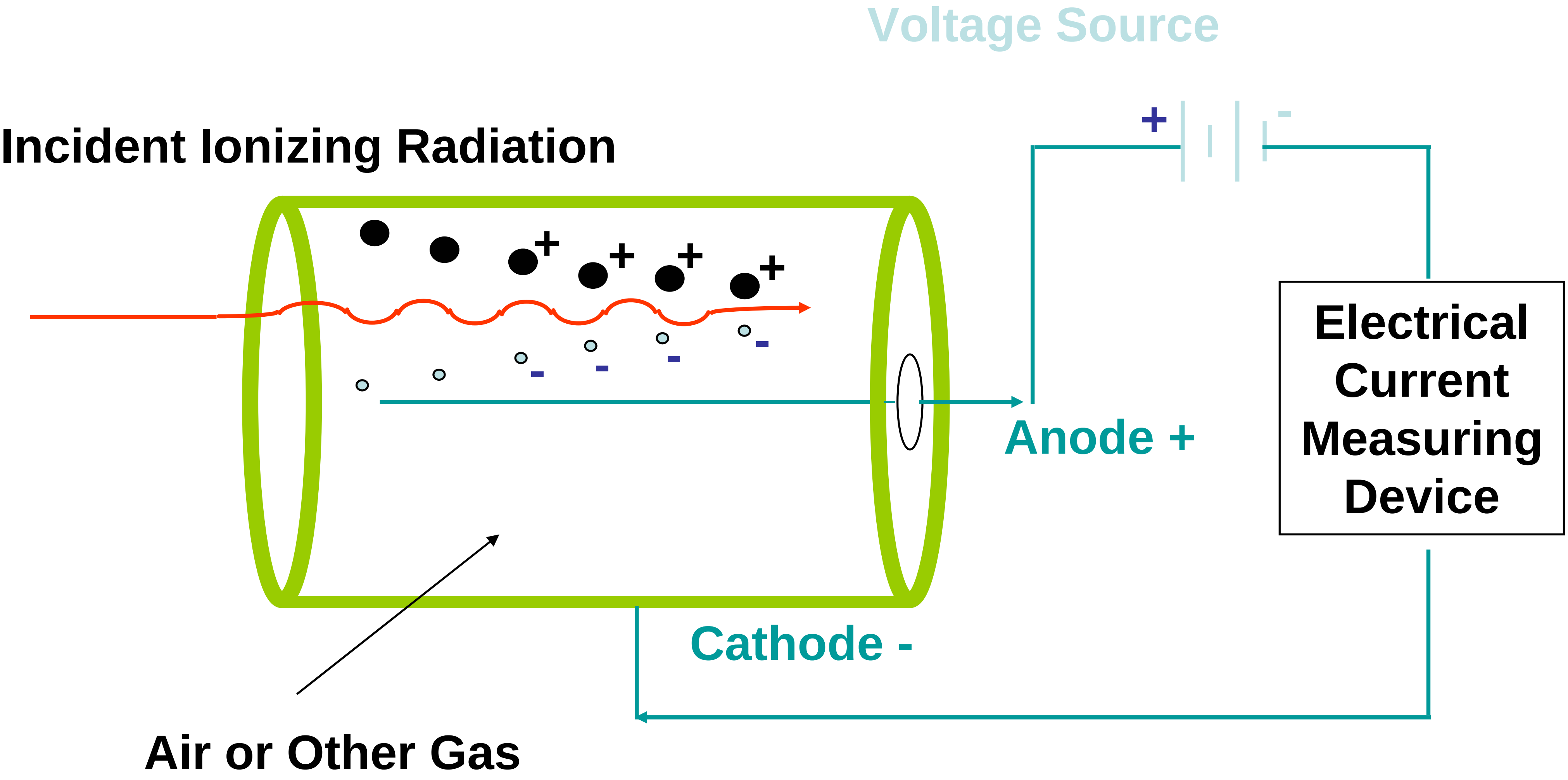
- **Estimating the severity of rad injury is difficult.**
  - Signs and symptoms: Rapid onset and greater severity indicate higher doses. Can be psychosomatic.
  - CBC with absolute lymphocyte count
  - Chromosomal analysis of lymphocytes
- **Treat symptomatically. Prevention and management of infection is the primary objective.**
  - Hematopoietic growth factors, e.g., GM-CSF, G-CSF (24-48 hr)
  - Antibiotics/reverse isolation
  - Electrolytes
- **Seek the guidance of experts.**
  - Radiation Emergency Assistance Center/ Training Site (REAC/TS)

Instruments

Detection of Radiation

- Most methods rely on the ions produced by the radiation
- Ions cause changes in the material or charge
- Detecting medium can be a solid, liquid or gas

Gas Filled Detectors



Voltage Source

Incident Ionizing Radiation

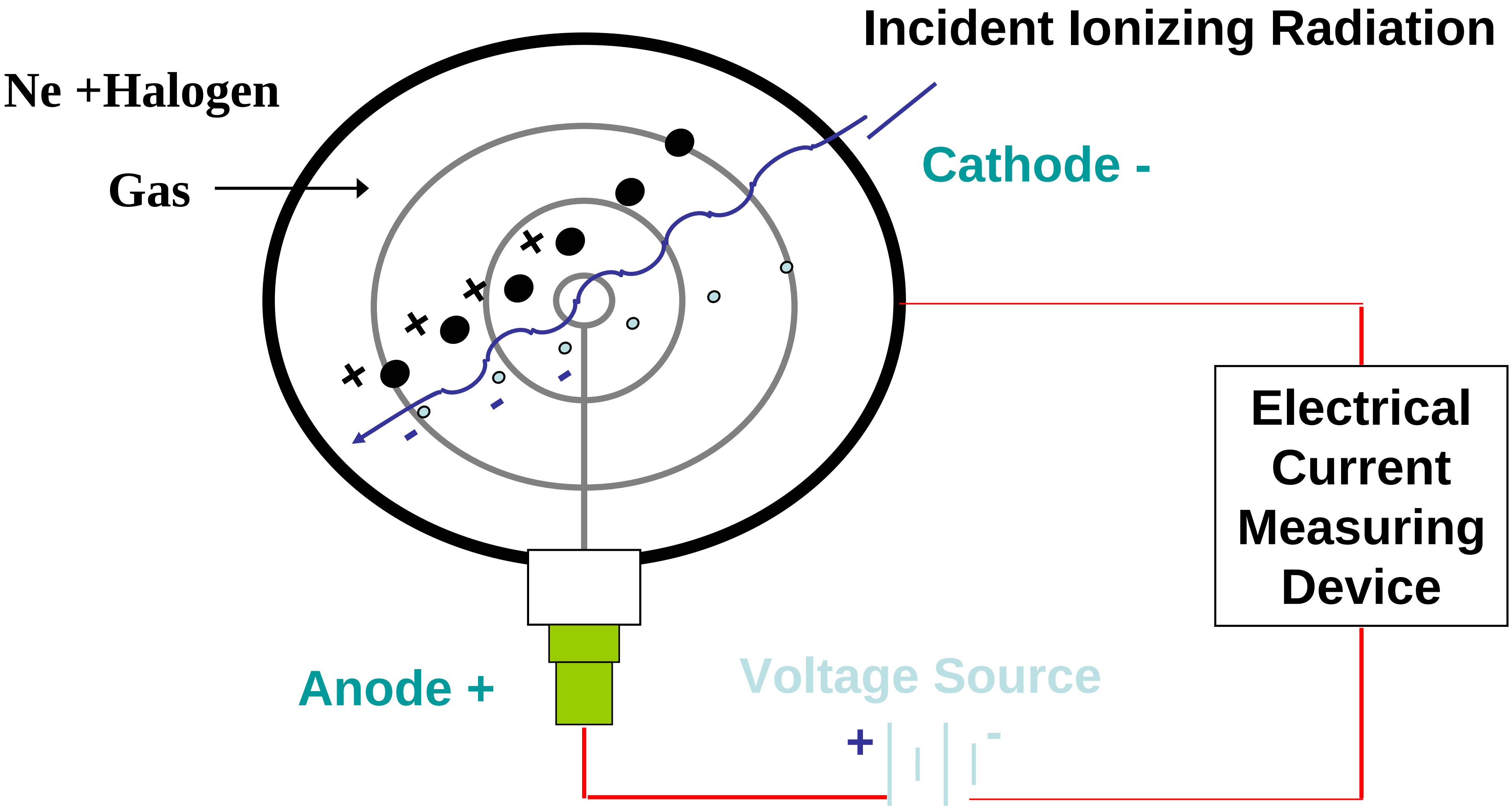
Anode +

Cathode -

Electrical Current Measuring Device

Air or Other Gas

Gas Filled Detectors



Incident Ionizing Radiation

Ne +Halogen

Gas

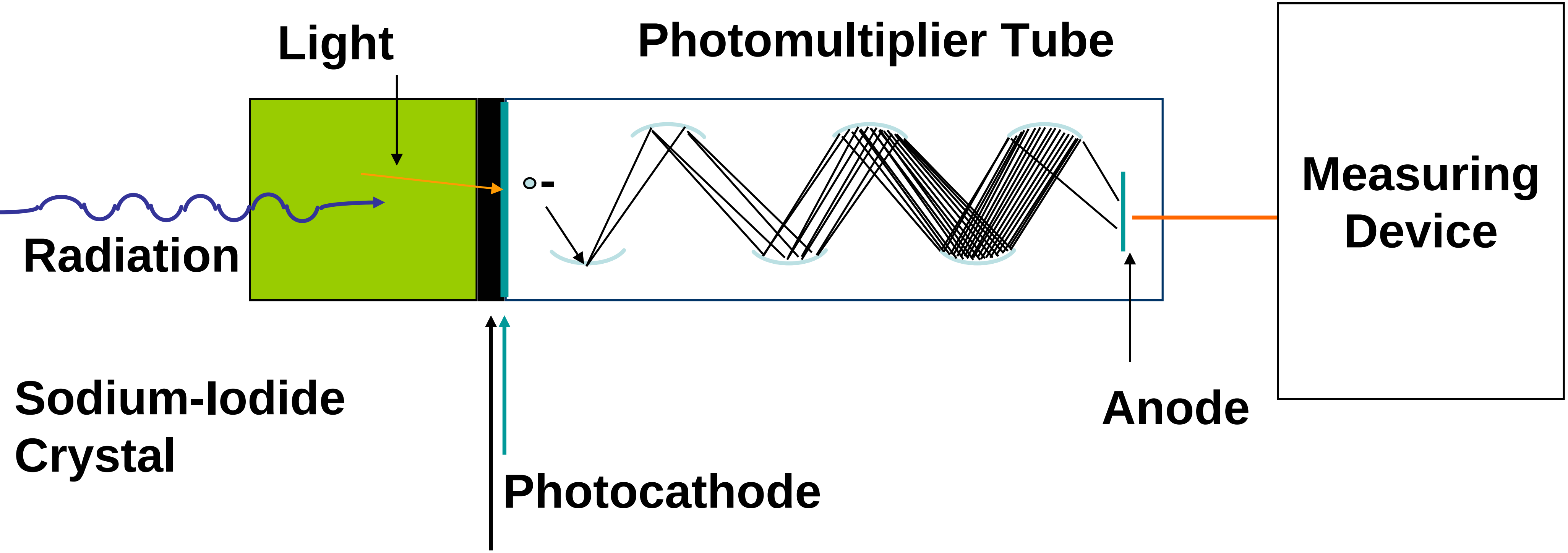
Cathode -

Electrical Current Measuring Device

Anode +

Voltage Source

Scintillation Detectors



Light

Photomultiplier Tube

Measuring Device

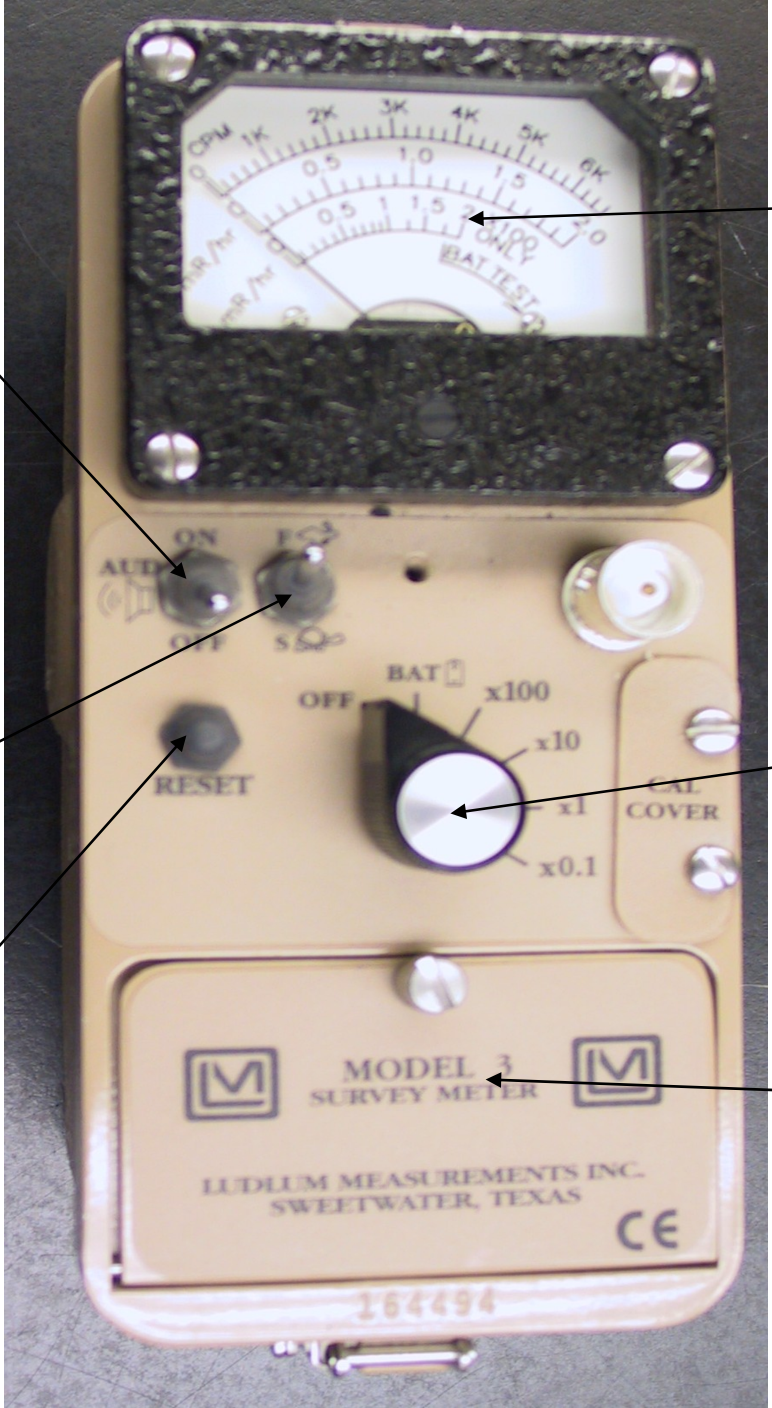
Radiation

Sodium-Iodide Crystal

Anode

Photocathode

Optical Window



Audio control

Faceplate

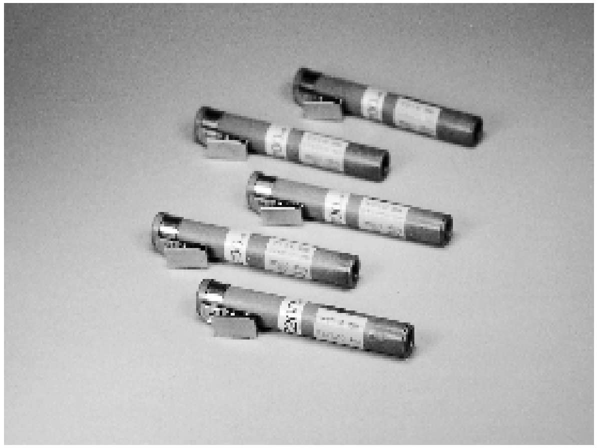
Rate control

Selector switch

Reset switch

Battery
Compartment

Personnel Monitoring



Radiation Dosimetry

The scientific determination of amount, rate, and distribution of radiation emitted from a source of ionizing radiation

biological - measuring the radiation-induced changes in a body or organism

physical - measuring the levels of radiation directly with instruments.

Types of Dosimeters

- Immediate Read
    - Pocket Ionization Chambers, Solid state detectors, handheld GM/Ionization detectors with dose accumulation function
- Delayed read / Personnel monitors
    - Film Badges, TLD (Thermo Luminescent Dosimeters), OSL (Optically Stimulated Light-emitting Dosimeters)

Biologic Monitoring

- Could be based on
  - Cytology – Blood, chromosome changes
  - Physiological symptoms
  - Other

Misc Monitoring

- Activation of metals
- Activation of materials (in vivo)
- Film
- TL of building materials
- Modeling

RDD

DANGER
660
RADIOACTIVE MATERIAL
SPECIAL FORM N.O.S.
NRC USA/9033/B( ) TYPE B
IAEA USA DOT RAM-0-78

Radiological Dispersion Device (RDD)

- A dirty bomb or a Radiological Dispersion Device (RDD) is a conventional explosive device that disperses radioactive material

Radionuclides considered for RDD

- Cobalt-60 (Co-60)
- Iodine-131 (I-131)
- Cesium-137 (Cs-137)
- Iridium-192 (Ir-192)
- Phosphorus-32 (P-32)
- Strontium-90 (Sr-90)
- Americium-241 (Am-241)
- Plutonium-239/238 (Pu)
- Uranium (U or DU)
- Thorium (Th-232)

Examples of Radioactive Materials

Radionuclide	**Physical Half-Life**	**Activity**	**Use**
Cesium-137	30 yrs	2000 Ci	Irradiator
Iridium-192	74 days	100 Ci	Industrial Radiography
Hydrogen-3	12 yrs	12 Ci	Exit Signs
Ho-166m	25 hr	2 Ci	Radiation Therapy
Y-90	10 days	0.1 Ci	Research/Therapy
Iodine-131	8 days	0.15 Ci	Nuclear Medicine Therapy
Technetium-99m	6 hrs	0.025 Ci	Diagnostic Imaging

RDD Effects

- Primary Effects
  - Damage from the primary explosive
  - Injuries related to the primary explosive
- Secondary Effects
  - Radiation Exposure from isotope (will generally not be enough to result in physical response)
  - Personnel contamination
  - Area Contamination
  - Fear Factor from potentially unknown radiation exposure

RDD Response

- Efforts will revolve around minimizing contamination, however medical emergencies will take precedence
- The spread of contamination is dependent on the following and hazard:
  - Amount of radioactivity
  - Physical form of material
  - Explosives used
  - Meteorological conditions
  - Type of radioactive material

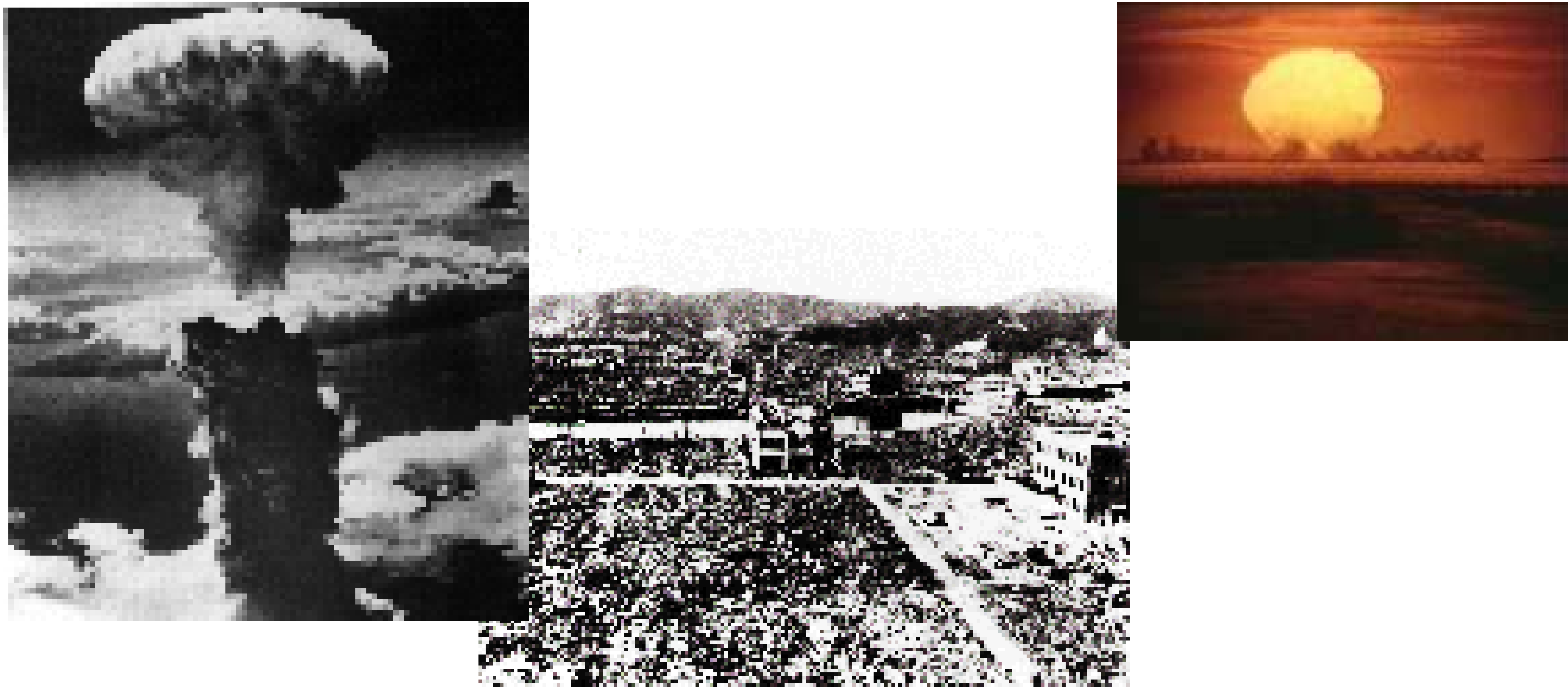
Potential consequences of dispersal of radioactive material into...

Facility ventilation systems
- Inhalation (Internal) Dose hazard
- Interruption of ‘normal life’
- Expensive cleanup costs

The general environment (“dirty bombs”, crop dusters, fire, sprayer, etc..)
- Low likelihood of acute radiological effects
- May require population shelter or evacuation
- May be difficult to clean outdoor areas

Water supplies
- High Dilution
- Individually significant doses would ***not*** likely result.

Nuclear Device



Nuclear Device

- Fission or Fusion based explosive
- Most devices are able to deliver over 100 kiloton yield
  - Hiroshima bomb was approximately 15 kilotons
- Results in significant radiological contamination of both the environment and victims
- Depending on the size of the weapon, those within 300 meters or so will receive not only lethal doses of radiation but also significant physical injuries

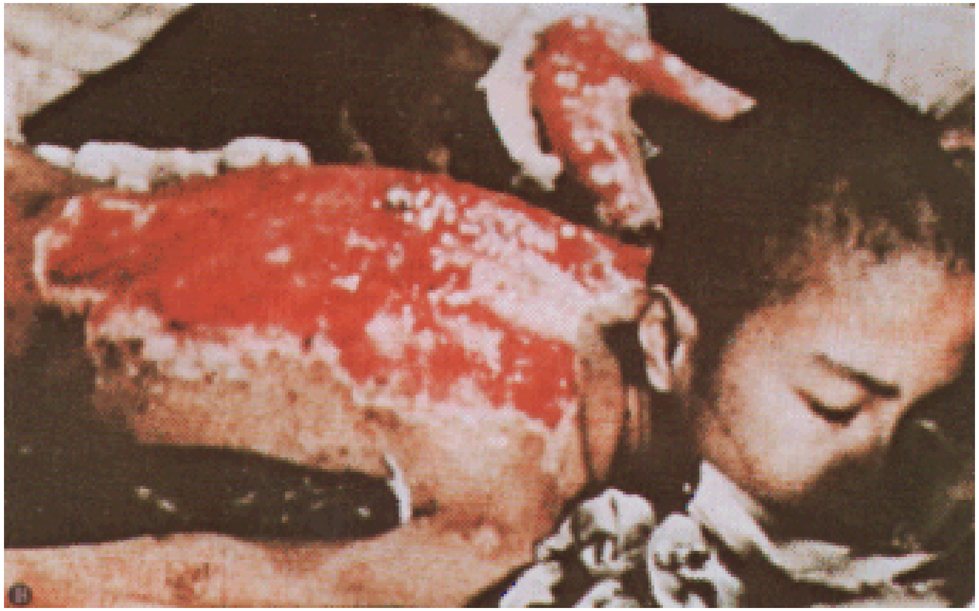
Nuclear Device

- Primary Effects
  - Physical Damage from detonation
  - Shockwave
  - Heat Wave (from 1000 meters for a small device up to several miles)
  - Flash burns (individuals)
  - Glass and other projectiles generated by the explosion
  - Radiation and Radioactive Contamination

Nuclear Device

- Secondary Effects
  - Radiation Dose Syndrome Effect from surviving victims
  - Radioactive Contamination
  - High level radiation doses to rescue workers
  - Fallout and prolonged restriction of affected area due to radiation
  - Psychological Impact of Nuclear Weapon usage
- EMP can potentially damage electronic communication adding the logistical issues

1945 Japan



Post Event Response

Emergency Response

- Evaluate (and re-evaluate at each step)
- Contain or cease
- Rescue
- Treat
- Decontaminate
- Recover

Evaluation

- What happened?
- Where did it happen?
- What isotope was involved?
- Form, amount, extent
- Area affected?
- Weather conditions?

Contain

- Shelter in place
- Evacuate
- Boundary

- Public Health orders
  - Food and water
  - Shelter
  - Medical attention

State DOH (PAR)

- Protective Action Recommendations (PARs) should be applied to locations and individuals within 1 mile from event until further information is gathered. Applies for 3 phases -
  - Phase I: Applies immediately and continues until we know more about the event, e.g. having the results from a sample, an instrument reading;
  - Phase II: Event is over in terms of explosion or initial distribution of radioactive material. The radiation hazard has been identified.
  - Phase III: Cleanup and full recovery. Food control restrictions if necessary.

State PARs cont

- Phase I – PARs 1-7
- Phase II – PARS 1-23

- PARS covers First Responders, Emergency Responders, and the Public

- For more info see DOH Publication:

  Protective Action Recommendations

  For a Radiological Dispersal Event Including Improvised Nuclear Devices

DOE Dose Rate Recommendations

Dose Rate	**Recommended Actions**
x2 Background	Contaminated Persons
1 – 5 mR/h	Hot Line (i.e. separate and decon)
0.001 – 10 R/h	Work in Hot Zone (personnel)
10 R/h	Turn Back (except for lifesaving)
200 R/h	Turn Back (even for lifesaving)

EPA Action Guidelines

Dose limit (whole body)	**Emergency Action Dose Guidelines Activity Performed**
5 rem	All Activities
10 rem	Protecting major property
25 rem	Lifesaving/protection of large populations
>25 rem*	Lifesaving/protection of large populations

*Full knowledge of the risk needed

Medical Treatments

- Centered around providing supportive care.
- Focus is on patient received radiation doses that are treatable (i.e. considered under 400-500 rad for mass casualties and 800 rad for limited victims)
- Care is centered upon the prevention of infections and minimization of secondary effects.

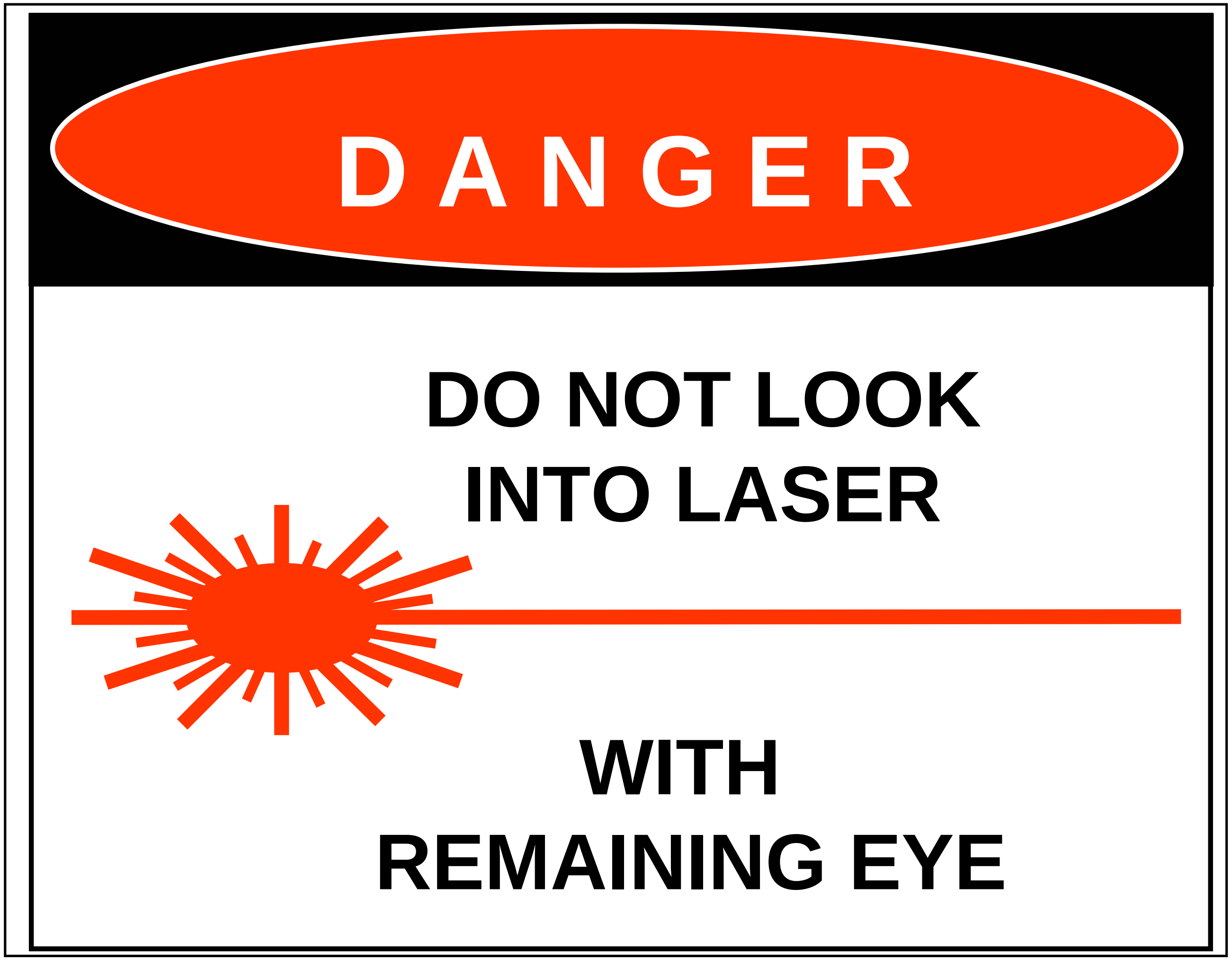
Actions for High Doses

- **Estimating the severity of rad injury is difficult.**
  - Signs and symptoms: Rapid onset and greater severity indicate higher doses. Can be psychosomatic.
  - CBC with absolute lymphocyte count
  - Chromosomal analysis of lymphocytes
- **Treat symptomatically. Prevention and management of infection is the primary objective.**
  - Hematopoietic growth factors, e.g., GM-CSF, G-CSF (24-48 hr)
  - Antibiotics/reverse isolation
  - Electrolytes
- **Seek the guidance of experts.**

Hospital Emergency Incident Command System (HEICS)

- For hospitals, HEICS will be initiated.
- Incident Command with consultation of the Radiation Safety Office providing expert consultation and coordinating the individual performing environmental risk analysis.
- Radiation Dose Limits will be followed along with recommended action guides from the DOE and EPA.
- Monitoring with portable instruments, instant read dosimeters and film badges.

Communications



DANGER

**DO NOT LOOK
INTO LASER**

**WITH
REMAINING EYE**

Things to Expect to Hear

- Units of dose (rad, Rem, Roentgen)
  - Possibly but not probably in SI units (Sv)
- Activity (Ci, mCi, kCi, uCi)
  - Possibly in SI units (Bq)
- Contamination (CPM, DPM, uCi/area)
- Isotopes (Cs-137, Pu-239, I-131)
- Dose Rates (R/hr, mrem/hr)
- Confusion

Prefixes

- Milli (m) is 1/1000
- Kilo (k) is 1000
- Mega (M) is 1,000,000
- Micro (µ) is 1/1,000,000

- See on-line handout for more info on terms

Example of Radiological Incident

- Note: this was not purposeful or terror related

Goiania September 1987

Loss of control of the source of a teletherapy unit and opening of the the capsule containing

1375 Ci of Cs-137

Cs-137: 30 year T1/2

0.662 keV gamma

514 keV beta

Goiania

- Two people entered the partially demolished medical center and, not knowing what the unit was but thinking it might have some scrap value, removed the source assembly from the machine. This they took home and tried to dismantle.
- In the attempt the source capsule was ruptured. The radioactive source was in the form of cesium chloride salt, which is highly soluble and readily dispersible.

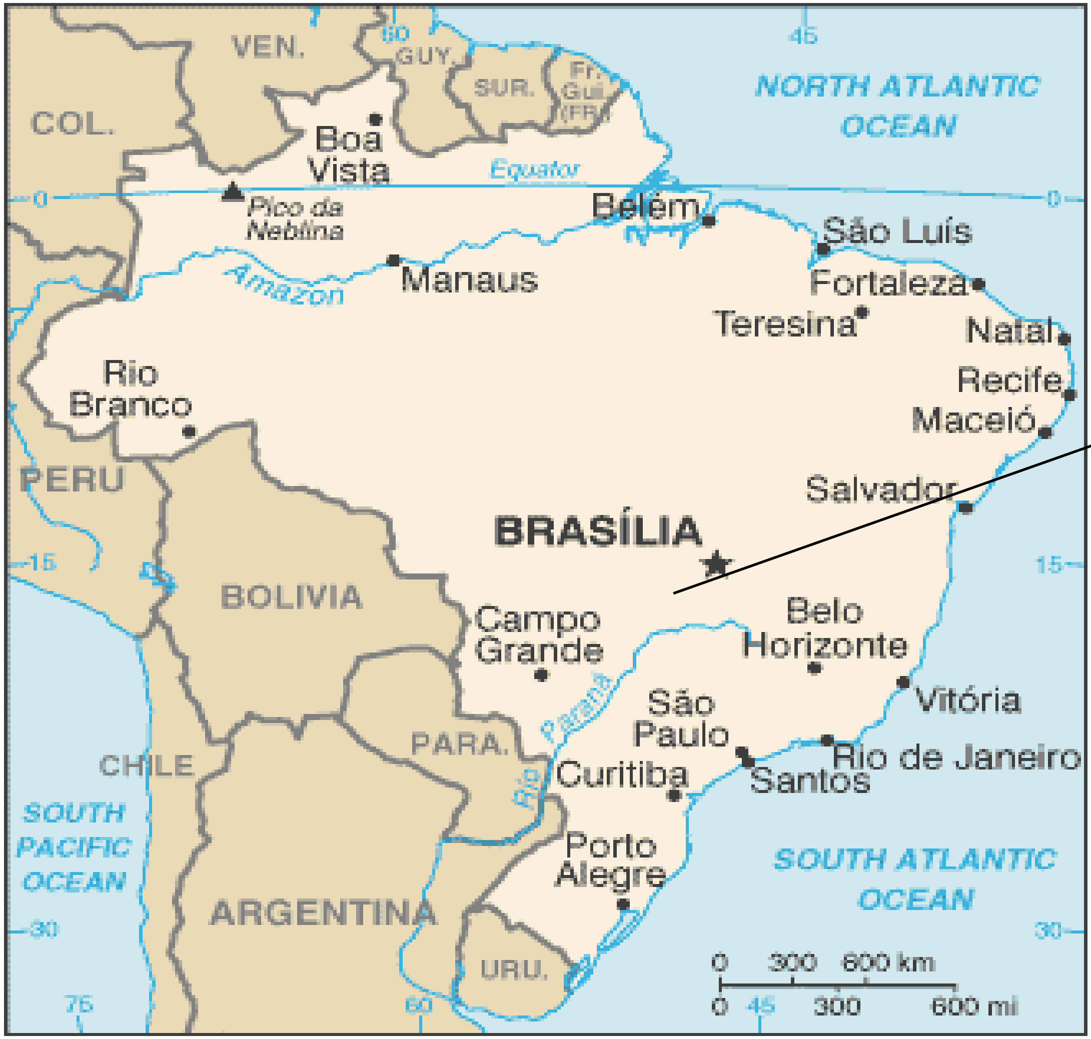
Goiania

- Contamination of the environment ensued, with one result being the external irradiation and internal contamination of several persons.
- After the source capsule was ruptured, the remnants of the source assembly were sold for scrap to a junkyard owner. He noticed that the source material glowed blue in the dark. Several persons were fascinated by this and over a period of days friends and relatives came and saw the phenomenon. Fragments of the source the size of rice grains were distributed to several families

Goiania

- This proceeded for five days, by which time a number of people were showing gastrointestinal symptoms arising from their exposure to radiation from the source.

Where is Goiania?



GOIANIA
125 miles from Brasilia.
Pop: 1.3 million

Public Perception

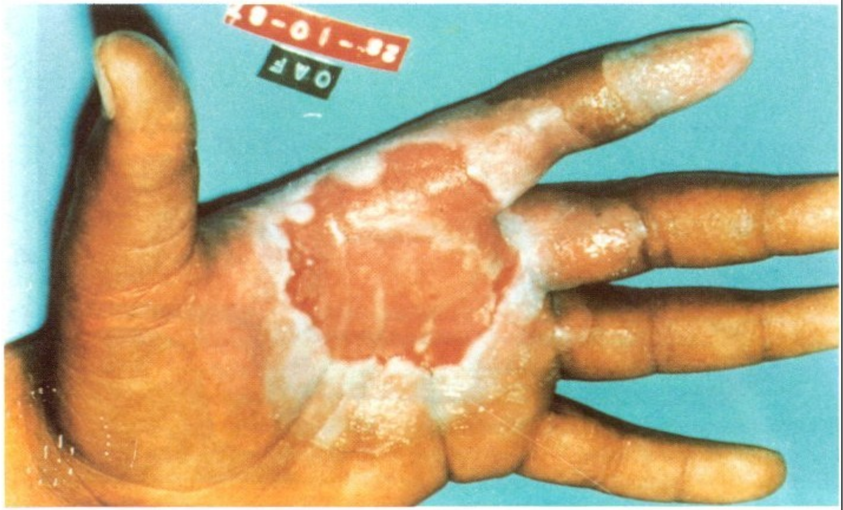
- These are comments by the people of the city
  - I do not understand what are you talking about and
  - I am afraid
  - The word cancer was one the most common word in the city

Main Questions Asked

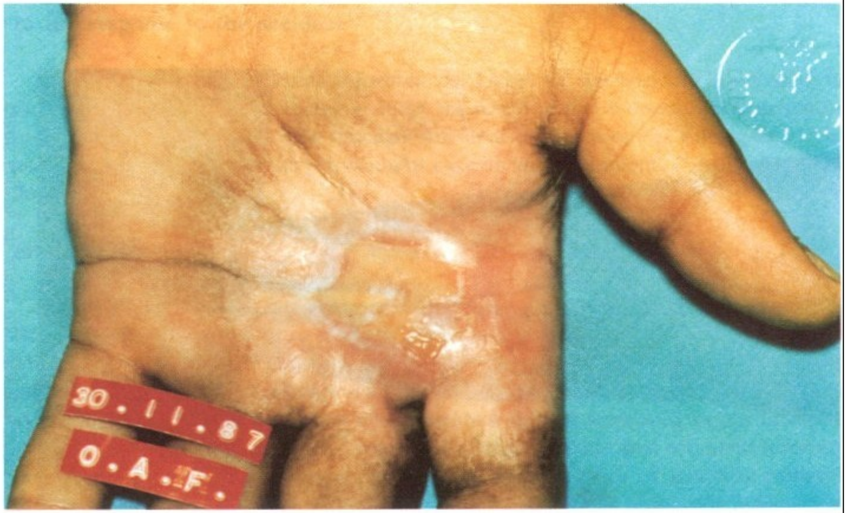
- How long will it take to feel any consequences?
- What are the effects on children and women?
- What are the effects on future generations?
- Please could you repeat it once again?
- Whom should I believe? Do you swear?
- Who is right? Who is exaggerating?
- How do we know whom to trust?

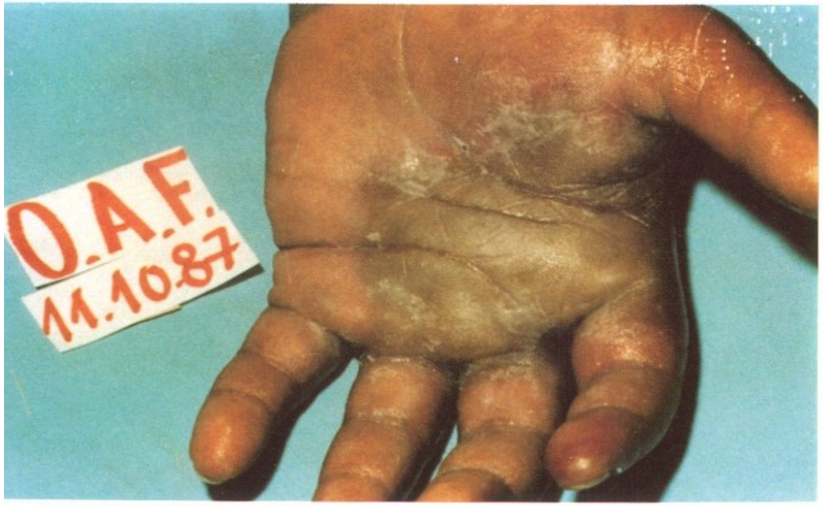
Recovery of the Source

- **Activity 50.9 TBq (1375 Ci) September 1987**
- **The best estimate for source recovery was 44 TBq or 1200 Ci.**



29. Bulla completely **broken down and** injury **index and middle** fingers





28. Large bulla **on** palmar surface **of** the hand. Note wet desquamation

Burns from Cs-137

Final Outcome of Goiania

- Four died within four weeks
  - total body radiation doses from 4.5 Gy to over 6 Gy.
- Two patients with similar estimated doses survive
- 20 hospitalized
- 112,000 persons were monitored,
  - 249 were contaminated either internally or externally.

Summary

- Radiation exposure is a part of everyday life
- Noticeable physiological effects from radiation do not occur at levels below 100 rem
- There are two principal radiological of concern
    - – Radiological Dispersal Device
    - – Nuclear Device

The Badguy’s Problems

- To get enough radioactive materials
- To get enough explosives
- Designing a dispersal device that works
- Getting the whole thing to a place of interest
- Setting it off

Our Problems

- Keep our radioactive materials secure
- In case of a bomb
  - Deal with the explosion and its effects
  - Deal with the contamination
    - People
    - Area
  - Deal with the public and workers actually affected
  - Deal with psychosomatic casualties

Summary

- Generally speaking medical intervention should always take precedence over decontamination
- Radioactive contamination hazards are only of significant physiological concern with Nuclear Devices.
- RDD are designed to induce fear – stay calm

Where to Get More Info

- General Information
  - www.physics.isu.edu/radinf
- State Radiation Control Office
  - www.doh.wa.gov/ehp/rp/
- Federal Nuclear Regulatory Commission
  - www.nrc.gov
- Radiological Emergency Web Resources
  - www.physics.isu.edu/radinf/spec.htm#em

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